UNLIMITED

TECH. MEMO
SPACE 373

ROYAL AEROSPACE ESTABLISHMENT

MEASUREMENTS OF THE SINGLE EVENT UPSET ENVIRONMENT IN THE UPPER ATMOSPHERE

by

C. S. Dyer

A. J. Sims

J. Farren

J. Stephen

November 1989

Procurement Executive, Ministry of Defence
Farnborough, Hampshire

CONDITIONS OF RELEASE

0067967 BR-113427

************************** DRIC U

************************** DRIC Y

Reports quoted are not necessarily available to members of the public or to commercial organisations.

ROYAL AEROSPACE ESTABLISHMENT

Technical Memorandum Space 373

Received for printing 23 November 1989

MEASUREMENTS OF THE SINGLE EVENT UPSET ENVIRONMENT IN THE UPPER ATMOSPHERE

by

C. S. Dyer

A. J. Sims

J. Farren*

J. Stephen*

SUMMARY

Regular flights of a Cosmic Radiation Environment Monitor on-board Supersonic Transport enable mapping of the atmospheric environment to 60000 ft. Results show the importance of secondary particles produced by nuclear reactions in the atmosphere.

* Nuclear Physics and Instrumentation Division, Harwell Lab, Oxfordshire, England

LIST OF CONTENTS

MEASUREMENTS OF THE SINGLE EVENT UPSET ENVIRONMENT IN THE UPPER ATMOSPHERE[1]

Dr C S Dyer, A J Sims
Space Department, Royal Aerospace Establishment,
Farnborough, Hampshire, England

Dr J Farren, Dr J Stephen
Nuclear Physics and Instrumentation Division,
Harwell Laboratory, Oxfordshire, England

Abstract

Regular flights of a Cosmic Radiation Environment Monitor on board Supersonic Transport enable mapping of the atmospheric environment to 60000 feet. Results show the importance of secondary particles produced by nuclear reactions in the atmosphere.

I. INTRODUCTION

Following the growing awareness of the potential hazards to spacecraft electronic systems from single event upsets caused by cosmic rays and trapped protons, it has recently been realised that the penetration of cosmic rays and their secondaries within the atmosphere can lead to such events in avionics and missile systems. Such upsets become increasingly likely as electronics becomes more sophisticated and moves to larger integration scales and smaller feature sizes. Particle fluxes increase towards the top of the atmosphere so that the electronics systems most at risk are those carried on supersonic aircraft and transatmospheric vehicles. In recent years a number of predictions have been made of the relevant particle environments, including heavy ions [1], neutrons [2], and mesons [3]. However to date there has been little comparison with environment measurements or correlation with upset observations.

For some years we have been developing packages for spaceflight to serve as a Cosmic Radiation Effects and Activation Monitor (CREAM). During the hiatus in spaceflight opportunities we have adapted a version for use on aircraft. With the kind cooperation of British Airways, flights have been commenced on the Supersonic Concorde, which flies to 60000 feet and follows routes which regularly cover the latitude range from 12° to 52° North. In this paper we report on the analysis of data taken from thirty flights made during November 1988 and January to February 1989 and yielding 51 hours of flight at altitudes greater than 50000 feet. Following an aircraft maintenance period the detector resumed regular flights on 5 June 1989 and is now accumulating high altitude data at the rate of about 10 hours per week.

II. THE CREAM EXPERIMENT

The CREAM packages were initially conceived for flight as a Shuttle mid-deck locker experiment with the aims of testing and improving the space radiation environment and shielding models used in the prediction of upset rates and induced radioactivity. An active box employing pin diode detectors will be used to obtain

real-time, energy-deposition spectra in silicon for a number of locations afforded various amounts of physical shielding, while passive detectors comprising particle-track detectors, metal activation foils and thermoluminescent dosimeters will obtain mission-integrated data at the same locations. A further version of the active detector has been combined with pMOS integrating dosimeters [4] to form a Cosmic Radiation Effects and Dosimeter (CREDO) experiment suitable for flight on free-flying spacecraft.

For the Concorde version the active detector is configured in a standard avionics box (an ARINC crate) which is accomodated in an avionics rack adjacent to the corridor running between the passenger section and the cockpit. When the plane is in level flight the diodes are horizontal and are afforded approximately 14 gm cm^{-2} of shielding from overlying material. This may be compared with atmospheric shielding of 72 gm cm^{-2} at 60000 feet and 120 gm cm^{-2} at 50000 feet. Power is taken from the aircraft 28V DC supply and the experiment is automatically switched-on when the undercarriage is raised and switched-off when it is lowered. A 12V back-up primary battery provides for orderly shut-down when the aircraft power is removed.

The active detector array comprises ten pin diodes operated at 172 μm depletion under 15 V reverse bias and connected in parallel to afford 10 cm^2 of sensitive area. A charge-sensitive amplifier generates a voltage pulse in proportion to the charge-deposition of the particle. Depending on the pulse amplitude, one of two possible further amplifications is selected in order to cover a wide range of charge depositions. An 8-bit, analogue-to-digital convertor is used and pulses are assigned into eight logarithmically spaced channels, or to an overflow channel, via an 80C31 microprocessor using accumulation times of 5 minutes. The charge deposition ranges of the channels have been calibrated using alpha-particles and fission fragments emitted from a Cf-252 source and the channel thresholds are given in Table 1 together with the equivalent Linear Energy Transfer (LET) for a particle incident normally to the diodes. Thus channel 1 accumulates events depositing between 19 and 46 fC and the overflow channel 9 records depositions in excess of 19.3 pC. A real-time clock records calendar time and data are stored in a 64K-by-8-bit, non-volatile RAM, which has sufficient capacity for some 200 flight hours. Typically data are retrieved once monthly via a lap-top computer and are analysed in conjunction with the flight-data records of altitude and position. Plastic track detectors comprising 100 cm^2 sheets of Kapton film and CR39 are also included on certain flights.

III. CONCORDE FLIGHTS

Of the thirty flights analysed in this paper eighteen were between London and New York and each of these afforded some 120 minutes at altitudes in excess of 50000 feet. A further three flights between London and Washington each yielded 140 minutes of high altitude data, while two flights between Washington and Miami provided 15 minutes each. Four short return flights based on London gave a total of 40 minutes at high altitude, while a round trip London-Shannon-Bridgetown-London gave 305 minutes of such data.

The routes are mapped in Figure 1, which also gives the contours of equal vertical cut-off rigidity for cosmic rays [1]. This rigidity is the threshold momentum-to-charge ratio required by a particle to penetrate the geomagnetic field and arrive in the vertical direction. It can be seen that for flights between London and New York or Washington

the cut-off rigidity varies between about 1.5 and 2.6 GV, while it reaches values of 5 GV for Miami and 11 GV for Bridgetown, Barbados.

IV. RESULTS

Adequate count statistics have been obtained to plot altitude profiles for channels 1 to 4 and these are presented in Figures 2 and 3. Because of the vast difference in geomagnetic latitude different symbols are employed for London to USA and London to Barbados. For channels 1 and 2 data points for all 5 minute accumulations are presented in Figure 2, while for channels 3 and 4 the data has been averaged over altitude spans of 5000 feet to improve the statistics and results are presented in Figure 3. Average count rates have been obtained for altitudes in excess of 50000 feet and these are presented in Table 1 for the 46 hours of data obtained on London to USA and London to London flights. For the 5 hours of London to Barbados flight time above 50000 feet the data show good statistics up to channel 6 with averages about 60% of the Table 1 rates.
Separating out the 30 minutes of Washington to Miami data gives counts in channels 1 to 6 which are 90% of the Table 1 rates.

V. DISCUSSION

The data of Figures 2 and 3, together with the average rates obtained at greater than 50000 feet, show a clear geomagnetic latitude effect when the Barbados routes are compared with North American routes. The difference for Miami is less statistically significant and it is difficult to sort out the altitude effect, but trends are in the right direction.

The count rates for channels 1 to 4 do not show a continuous increase with altitude and in fact show a possible maximum between 50000 and 60000 feet. This is indicative of secondary radiations which are produced by primary cosmic rays undergoing nuclear reactions in the atmosphere and which build-up to a Pfotzer maximum [5] at around 55000 feet before attenuating down to sea level.

In Table 1 the observed count rates are compared with a simple prediction based on the cosmic-ray heavy ion model of Adams [6] propagated through the atmosphere to depths of 50000 and 60000 feet for cosmic-ray cut-off rigidities of 1 and 2 GV. In this simple prediction particles are removed when they undergo nuclear reactions and no secondaries are included. However the path length distribution through the device is fully modelled assuming isotropic incidence. It can be seen that up to channel 5 the predictions are far too low. The predictions of Tsao et al [1] include energetic heavy secondary fragments and yet still significantly underestimate the data up to channel 5. For channel 6 the observation is in reasonable agreement with the heavy ion prediction, while for channel 7 one count has been recorded. Channels 8 and 9 have yet to record a count, while the predicted count totals for 51 hours of flight would be at most 2 and 0.4 respectively. Thus the null result obtained to date is not yet at variance with the prediction. Accumulation of a full year's flight data will give an order of magnitude more time and will allow testing of the heavy ion model for the higher channels.

For channels 1 to 5 it would appear that secondary protons, alphas, neutrons and possibly electrons considerably enhance the upset environment at these altitudes. A full radiation transport simulation is required and work has been initiated. However simple calculations suggest that the most likely contribution to channels 1 and 2 is from slow protons of energy less than 60 MeV at a flux of about 0.4 cm^{-2} s^{-1}. A relativistic

electron flux of 4 cm^{-2} s^{-1}, which has been reported for this altitude [7], could contribute around 20% via oblique incidence events. The events in channels 3 to 5 could be due to neutron reactions [2] and the required flux of around 10 cm^{-2} s^{-1} is of the right order for these altitudes [8]. Such enhancements by secondary radiations are also to be expected at significant shielding depths on Space Shuttle and it will be most beneficial to compare data obtained in a number of environments.

Thus far there have been no upsets recorded in the microprocessor (80C31) or memory (HM6167) incorporated in the experiment. Based on the environment data obtained to date and limited data on upset cross-sections for similar devices, it is estimated that upsets will occur at a rate of approximately one per 50000 flight hours.

VI. ACKNOWLEDGEMENTS

We gratefully acknowledge the help of British Airways staff and in particular the Flight Data Recording Section. R Hutchings and K O'Mahony of RAE have assisted in the integration and data retrieval, while at Harwell the design and build of the instrument have involved B Stimpson, B Ward, A Ellaway and A Shepherd.

VII. REFERENCES

[1] C H Tsao, R Silberberg and J R Letaw, IEEE Trans on Nuc Sci, NS-31, 1066, Dec 1984.

[2] R Silberberg, C H Tsao and J R Letaw, IEEE Trans on Nuc Sci, NS-31, 1183, Dec 1984.

[3] J F Dicello, M E Scillaci, C W McCabe, J D Doss, M Paciotti, P Berardo and J F Dicello III, IEEE Trans on Nuc Sci, NS-32, 4201, Dec 1985.

[4] A Holmes-Siedle, L Adams, S Marsden and B Pauly, IEEE Trans on Nuc Sci, NS-32, 4425, Dec 1985.

[5] G Pfotzer, Z. Phys., 102, 23, 1936.

[6] J H Adams, Jr, R Silberberg and C H Tsao, NRL Memorandum Report 4506, 1981.

[7] Exposure of the Population in the United States and Canada from Natural Background Radiation, NCRP Report No 94, Dec 1987.

[8] L L Newkirk, Journal of Geophysical Research, Vol 68, No 7, April 1963.

TABLE 1

DETECTOR RATES AT GREATER THAN 50000 FEET COMPARED WITH HEAVY ION PREDICTION

CHANNEL NO	CHARGE THRESHOLD (pc)	LET THRESHOLD (MeV/gm cm^{-2})	OBSERVED COUNTS (per 5 min) London to USA	STATISTICAL ERROR	PREDICTED COUNTS 50000 ft CUT-OFF RIGIDITY		PREDICTED COUNTS 60000 ft CUT-OFF RIGIDITY	
					1 GV	2 GV	1 GV	2 GV
1	1.9×10^{-2}	10.1	568.0	±1.0	18.4	10.7	41.2	28.1
2	4.6×10^{-2}	26.0	58.5	±0.3	8.1	2.8	10.4	5.4
3	0.11	60.1	16.7	±0.2	1.4	0.85	3.3	2.0
4	0.26	144.0	5.2	±0.1	0.36	0.26	1.2	0.9
5	0.61	340.0	1.10	±0.05	7.8×10^{-2}	6.5×10^{-2}	0.33	0.28
6	1.5	813.0	0.15	±0.02	1.5×10^{-2}	1.3×10^{-2}	8.2×10^{-2}	7.1×10^{-2}
7	3.4	1920.0	2×10^{-3}	$\pm2 \times 10^{-3}$	2.8×10^{-3}	2.6×10^{-3}	1.9×10^{-2}	1.8×10^{-2}
8	8.1	4570.0	Nil	-	4.7×10^{-4}	4.5×10^{-4}	3.7×10^{-3}	3.5×10^{-3}
9	19.3	10800.0	Nil	-	7.7×10^{-5}	7.5×10^{-5}	7.0×10^{-4}	6.8×10^{-4}

Concorde Routes

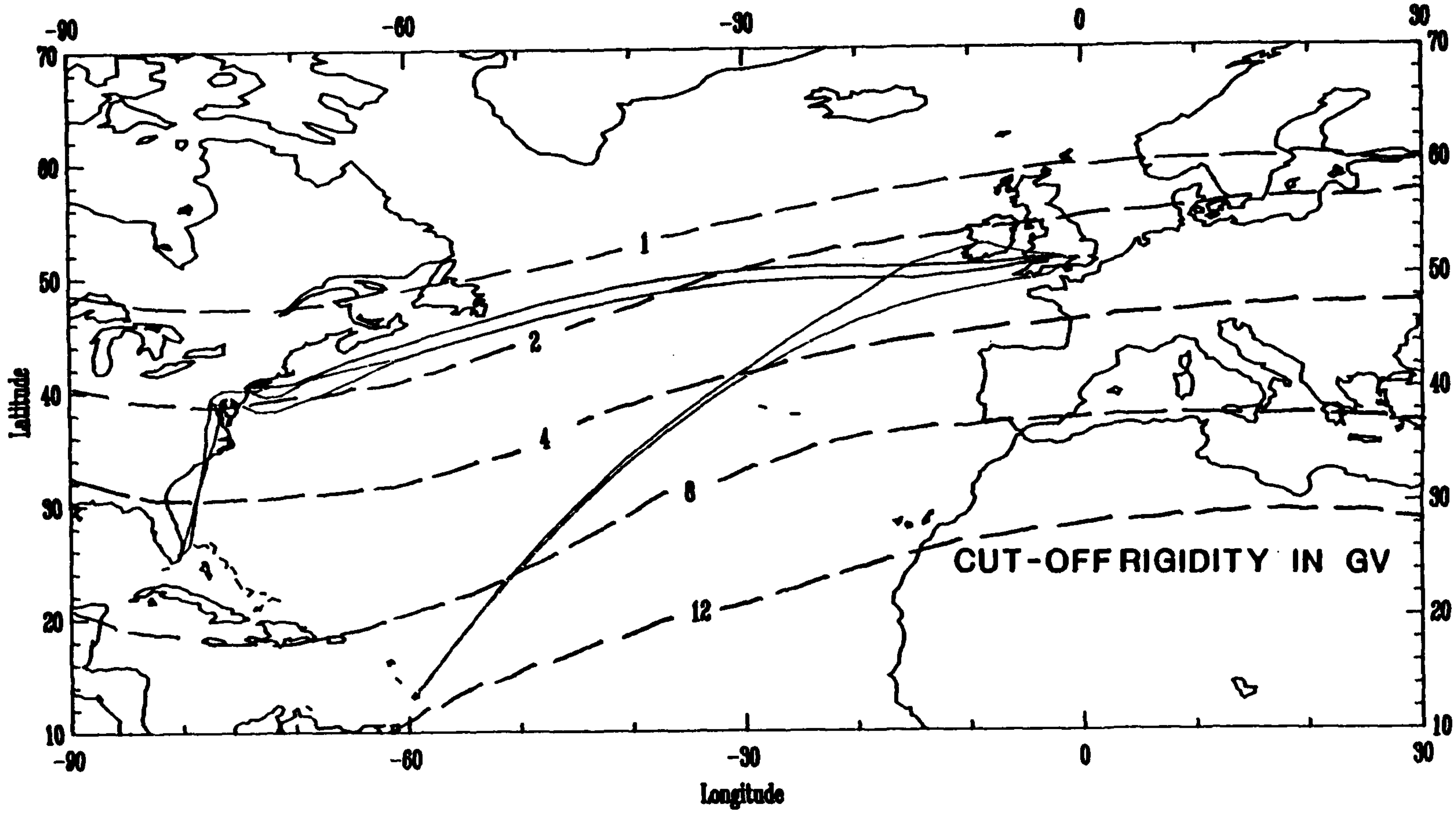

Fig 1 Concorde routes used in the analysis are shown together with contours of equal vertical cut-off rigidity for cosmic rays

Fig 2

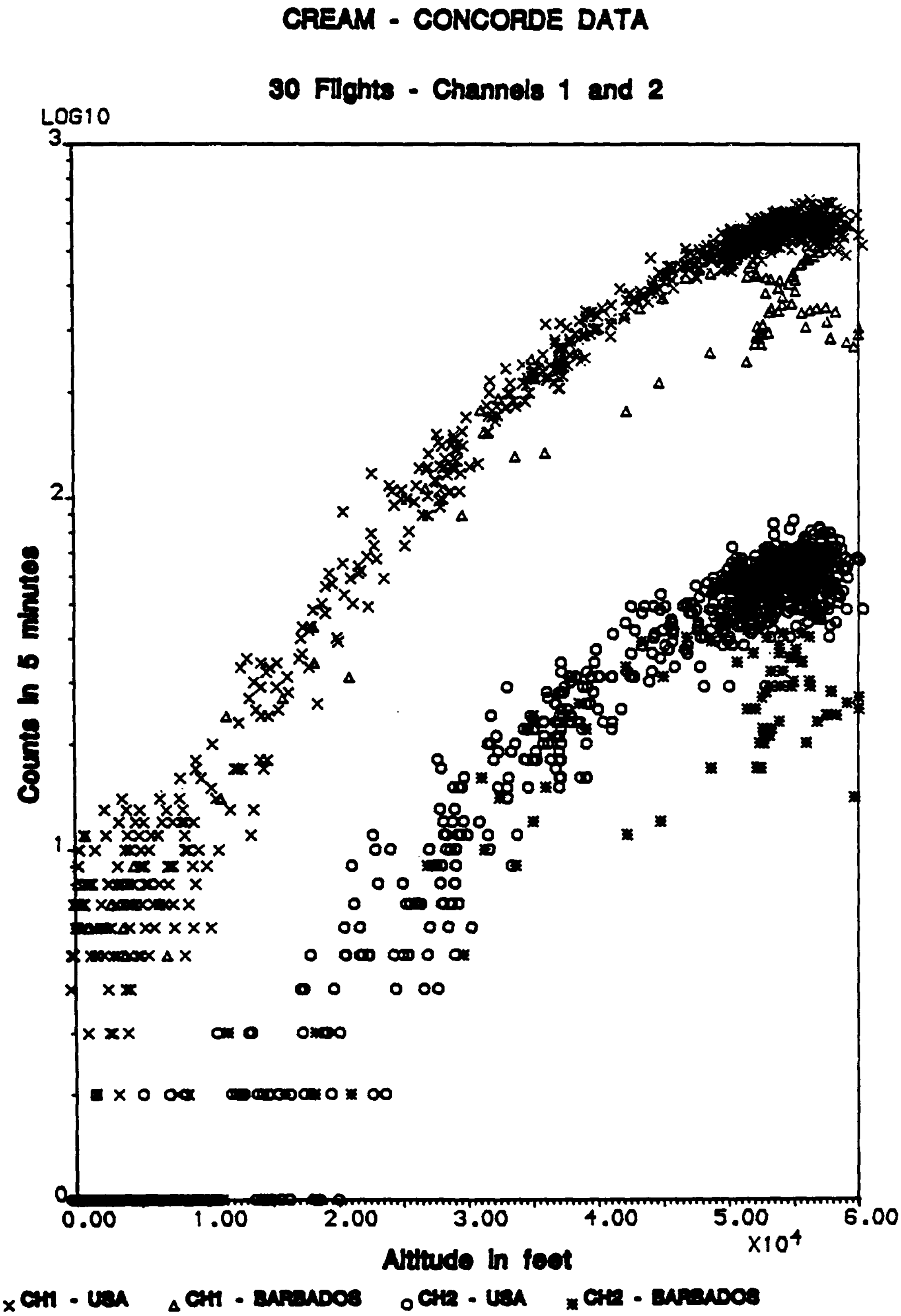

Fig 2 All data points for channels 1 and 2 are plotted against altitude. Different symbols are used for Barbados flights and show a reduction in rates with increased rigidity

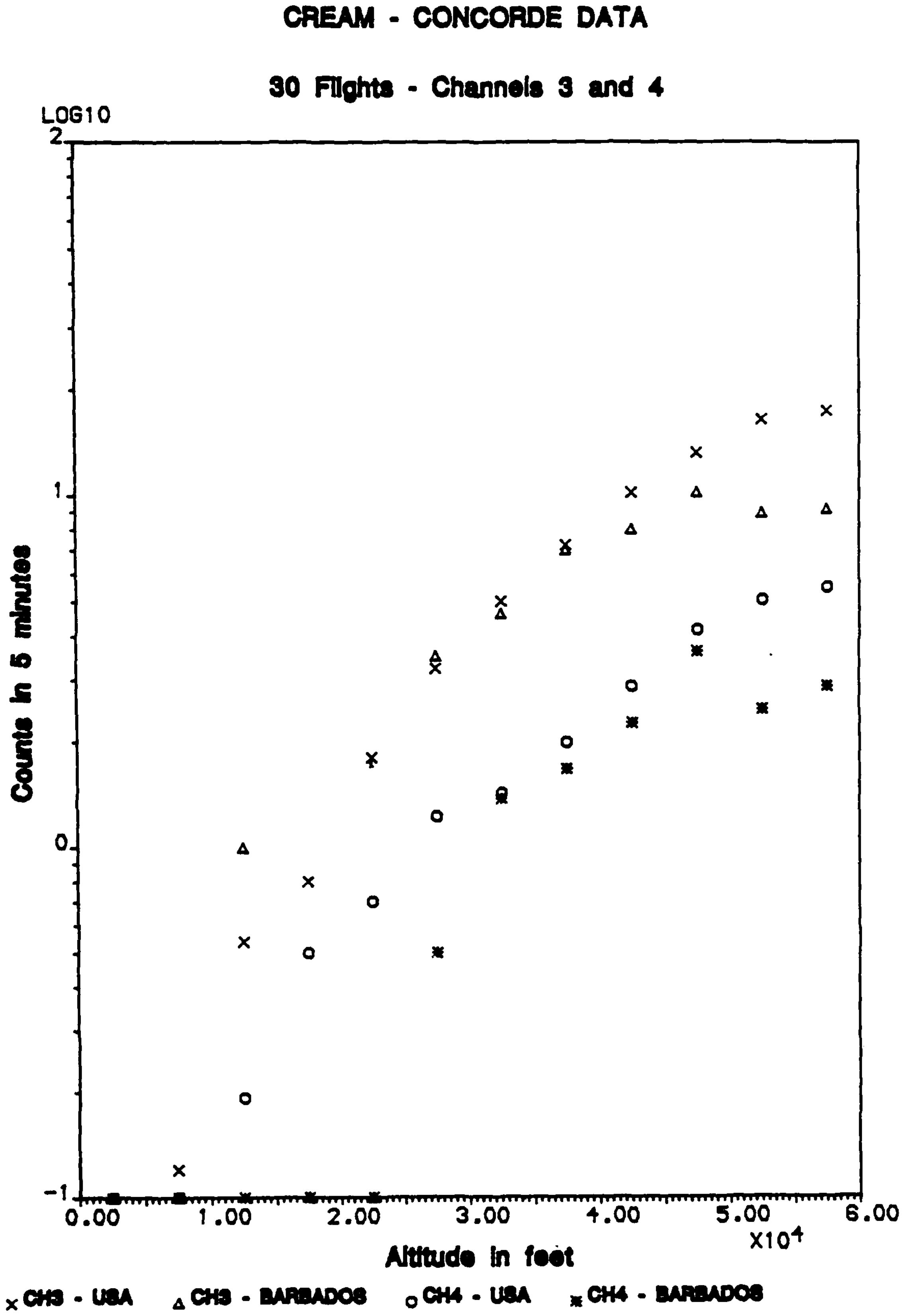

Fig 3 For channels 3 and 4 data are summed over 5000 feet altitude spans to improve statistics. Again a rigidity dependence is seen

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNLIMITED

As far as possible this page should contain only unclassified information. If it is necessary to enter classified information, the box above must be marked to indicate the classification, e.g. Restricted, Confidential or Secret.

1. DRIC Reference (to be added by DRIC)	2. Originator's Reference RAE TM Space 373	3. Agency Reference	4. Report Security Classification/Marking UNLIMITED

5. DRIC Code for Originator 7673000W	6. Originator (Corporate Author) Name and Location Royal Aerospace Establishment, Farnborough, Hants, UK
5a. Sponsoring Agency's Code	6a. Sponsoring Agency (Contract Authority) Name and Location

7. Title Measurements of the single event upset environment in the upper atmosphere

7a. (For Translations) Title in Foreign Language

7b. (For Conference Papers) Title, Place and Date of Conference
IEEE Nuclear and Space Radiation Effects Conference, Marco Island, Florida, USA, 24-28 July 1989

8. Author 1. Surname, Initials Dyer, C.S.	9a. Author 2 Sims, A.J.	9b. Authors 3, 4 .... Farren, J. Stephen, J.	10. Date November 1989	Pages 10	Refs. 8
11. Contract Number	12. Period	13. Project	14. Other Reference Nos.		

15. Distribution statement
(a) Controlled by – Head of Space Dept
(b) Special limitations (if any) –
If it is intended that a copy of this document shall be released overseas refer to RAE Leaflet No.3 to Supplement 6 of MOD Manual 4.

16. Descriptors (Keywords) (Descriptors marked * are selected from TEST)
Great Britain,
Single event upsets, Cosmic rays, Microelectronics, Supersonic transport, Atmospheric neutrons, Cosmic Radiation Effects and Activation Monitor (CREAM)

17. Abstract

Regular flights of a Cosmic Radiation Environment Monitor on-board Supersonic Transport enable mapping of the atmospheric environment to 60000 ft. Results show the importance of secondary particles produced by nuclear reactions in the atmosphere.